Signals of a first order phase transition: strangeness trapping

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One of the major goals of relativistic heavy-ion research is to explore the equation of state of strongly interacting matter, particularly its phase structure. Depending on the beam energy, various regions of temperature and baryon density can be explored. Lattice QCD results, suggest the presence of a first-order phase transition line at finite chemical potential as well as the existence of a critical end-point, though its precise location is not well determined.

Unlike most observables around $20-30$ AGeV beam energy there appears to be a significant enhancement of the K-to-π ratio. Furthermore, at the same energy, the fluctuation of this ratio is strongly enhanced if compared to mixed events. Though otherwise rather successful in describing the hadron yields, statistical models cannot reproduce the observed energy dependence. If these strong fluctuations resulted from the enhanced fluctuations associated with a second order phase transition, one would expect particularly strong fluctuations also in the pions. However, the fluctuations of the p-to-π ratio follow the expectations from transport models.

If the statistical models, indeed provide reasonable estimates for the relation between beam energy and the thermodynamic parameters characterizing the chemical freeze-out, *i.e.* the temperature and the chemical potentials. Then the the anomalous behavior would be consistent with the occurrence of a first order-phase transition *prior* to the chemical freeze-out [1]. A universal feature of first-order phase transitions is the occurrence of spinodal decomposition. This phenomenon occurs when bulk matter, by a sudden expansion or cooling, is brought into the region of phase coexistence. Since such a configuration is thermodynamically unfavorable the uniform system prefers to reorganize itself into spatially separate single-phase domains. Moreover, since this spinodal phase separation is accomplished by means of the unstable collective modes, the resulting domain pattern tends to have a characteristic scale equal to that of the most unstable modes.

We assume that the matter created in a heavy-ion collision undergoes such a decomposition, and somehow breaks into a number of subsystems, blobs, which subsequently expand and hadronize independently. The essential feature of such a scenario is that if the breakup is sufficiently rapid, then whatever strangeness happens to reside within the region of the plasma that forms a given blob will effectively become trapped and, consequently, the resulting statistical hadronization of the blob will be subject to a corresponding canonical constraint on the strangeness. This will lead to an enhancement of the multiplicity of strangeness-carrying hadrons, as compared to the conventional scenario where global chemical equilibrium is assumed, since the presence of a finite strangeness in the hadronizing blob enforces the production of a corresponding minimum number of strange hadrons.

If a given plasma blob is only a small part of the total plasma, its statistical properties may be treated in the grand-canonical approximation, in which the various species are independent. The multiplicity distribution of the s and $\bar{s}$ quarks in a blob (ν_s and $\nu_{\bar{s}}$) is then governed by the grand canonical partition function. In our canonical scenario, we typically consider plasma blobs of volume $V_q = 50$ fm^3. Their strangeness content S_0 is determined by sampling ν_s and $\nu_{\bar{s}}$ at the plasma temperature T_q, which is either taken to be equal to T_0 (the phase transition temperature) or to the hadronic freezeout temperature $T_h(\mu_B)$ (the dependence of the freezeout temperature on the chemical potential is determined by fitting hadronic yields). Each particular value of S_0 characterizes a canonical subensemble whose baryon number, charge, and strangeness will be reflected in the resulting collection of hadrons. The blob then expands until the freezeout volume $V_h = \chi V_q$ is reached. At this point, the blob hadronizes according to the canonical distribution associated with the particular value of S_0 In Fig. 1 the corresponding multiplicity variances are shown for the positive kaons. The overall behavior is qualitatively similar to the behavior of the averages. One notes a large enhancement over both the standard grand canonical approach and the case where a strong canonical constraint of $S_0 = 0$ is imposed on the blob (referred to as the restricted canonical treatment). As the pions are barely affected by this trapping of strangeness, they remain more or less unchanged from the standard grand canonical scenario, thus the K-to-π ratio is also enhanced. For further details see Ref. [1].

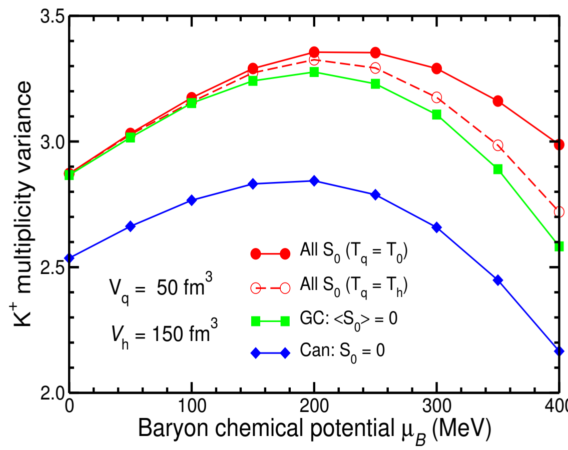

FIG. 1: The variance in the K^+ multiplicity as functions of the baryon chemical potential μ_B in three three scenarios: 1) the standard grand-canonical treatment, 2) the canonical treatment in which the blob strangeness S_0 is conserved through the hadronization, 3) the restricted canonical treatment admitting only $S_0 = 0$. We show results for $T_q = T_0$ or T_h in the canonical scenario. See text for details.

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